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An empirical evaluation of free BEM solvers for M/EEG forward modeling



A. GRAMFORT[†], T. PAPADOPOULOU[‡], E. OLIVI[‡], M. CLERC[‡]

alexandre.gramfort@inria.fr

[†] Parietal Project Team, INRIA Saclay-Ile de France, Saclay, France

[‡] Athena Project Team, INRIA Sophia-Antipolis, France



Objective

■ Evaluate the accuracy of available BEM solvers for M/EEG forward modeling with realistic head models.

The M/EEG forward problem

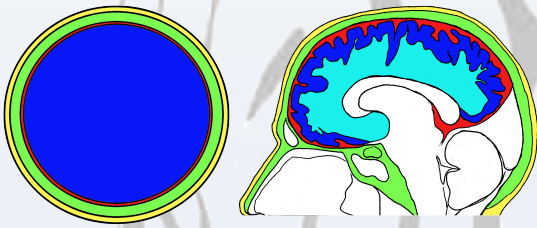
Objective

Predict what is measured by M/EEG sensors due to a configuration of current generators within the head.

Challenge

Analytical solutions exist for simple models such as sphere models. With realistic head models, numerical solvers are required. BEM solvers are adapted to models with piecewise constant conductivities.

Sphere models vs. realistic models



Why compare BEM solvers?

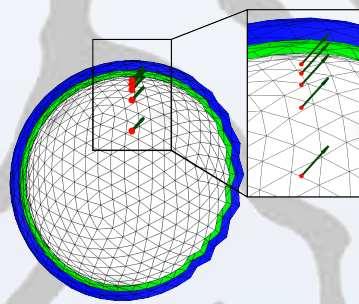
- BEM solvers are based on **different mathematical formulations**.
- For a given formulation, **implementation details** vary:
 - Galerkin methods vs **collocation** methods
 - Precision in **numerical integrations**
 - **Adaptive vs. non adaptive** integration procedures

Experimental setting

Software packages tested

- **OpenMEEG** with and without adaptive integration (**OM** and **OMNA**) [1,2,3]: Symmetric BEM with P1-P0 elements.
- **BEMCP** (**CP**) [Phillips 00]: standard BEM + ISA with constant collocation
- **Helsinki BEM** (**HB**) [Stenroos et al. 07]: same as BEMCP
- **Simbio** (**SB**) [Zanow et al. 95]: std. BEM + ISA with linear collocation
- **Dipoli** (**DP**) [Oostendorp et al. 89]: same as Simbio

Model considered



- **3 nested shells**: inner skull, outer skull and skin surfaces (radii 88, 92, 100).
- **5 dipoles** at different distances from the inner skull: direction (1, 0, 1)
- **regular and random meshes**
- a **random mesh** with N vertices is obtained by meshing the convex hull of $10N$ points randomly sampled on the unit sphere followed by decimation.

Simulation study: Comparison results for EEG

Precision measures

- Numerical solution g_n
- Analytical solution g_a
- Relative Difference Measure (RDM):

$$RDM(g_n, g_a) = \left\| \frac{g_n}{\|g_n\|} - \frac{g_a}{\|g_a\|} \right\|$$

Should be **close to 0**

- Magnitude (MAG):

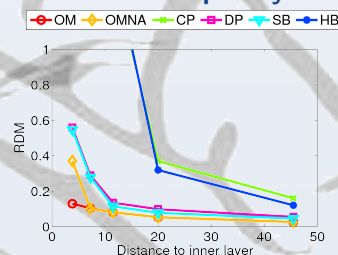
$$MAG(g_n, g_a) = \|g_n\| / \|g_a\|$$

Should be **close to 1**

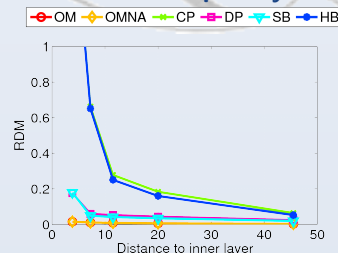
- With **random meshes** RDMs and MAGs are computed with **100 repetitions** of the experiment.
- **Note**: MEG accuracy relies on EEG solutions via the Biot et Savart law

With standard meshes

162 vertices per layer

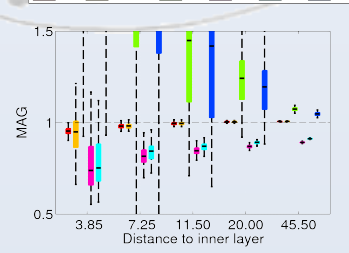
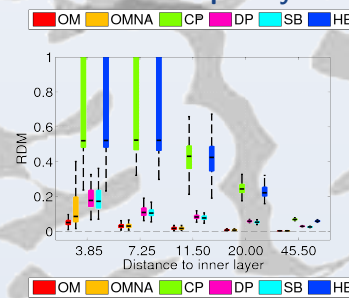


642 vertices per layer



With random meshes

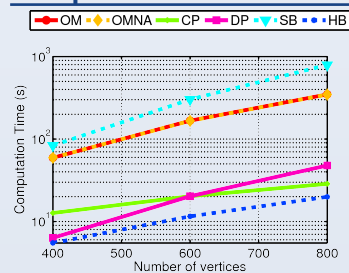
800 vertices per layer



- **OpenMEEG** is the **most accurate** solver with regular meshes.

- **OpenMEEG** with **adaptive integration** is the most robust to imperfect meshing.

Computation times



Technical details

- **OpenMEEG** is **opensource** (Linux, Windows, Mac OS X)
- **OpenMEEG** is written in C++ and can be used from **Python** and **Matlab** using the Fieldtrip toolbox
- Experiments have been performed with Fieldtrip
- <http://openmeeg.gforge.inria.fr>
- openmeeg-info@lists.gforge.inria.fr

References

- [1] Gramfort A., Papadopoulou T., Olivi E., Clerc M. **OpenMEEG: opensource software for quasistatic bioelectromagnetics**, submitted.
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- [3] Kybic J., Clerc M., Abboud T., Faugeras O., Keriven R., Papadopoulou T. **A Common Formalism for the Integral Formulations of the Forward EEG Problem**, IEEE Transactions on Medical Imaging, 2005